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(54) **TRANSPARENT STRUCTURES FILLED WITH ELECTRICALLY ACTIVE FLUID**

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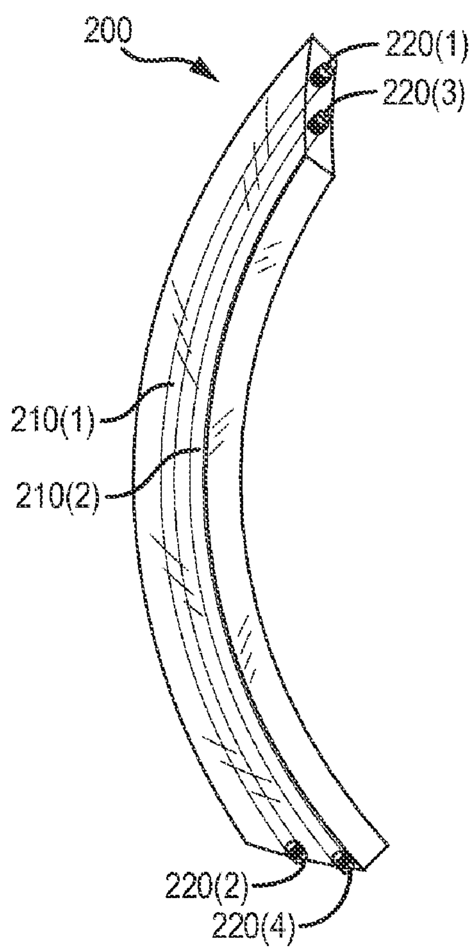
(52) **U.S. Cl.**

CPC ***G02F 1/133377*** (2013.01); ***H05K 9/0071*** (2013.01); ***G01D 5/12*** (2013.01); ***H01B 7/0027*** (2013.01); ***G02F 1/133528*** (2013.01); ***G02F 1/1336*** (2013.01); ***G02F 1/133514*** (2013.01); *G02F 2001/133624* (2013.01)

(57) **ABSTRACT**

Transparent structures containing a transparent electrically conductive fluid are used for aesthetically appealing designs and/or improved fatigue performance. Some structures have multiple isolated conductors while others have a single conductive area that may be used as a transparent antenna or a transparent EMI shield. Other embodiments employ fluids that change crystalline structure under an applied voltage such that a structure can change color and/or display a message.



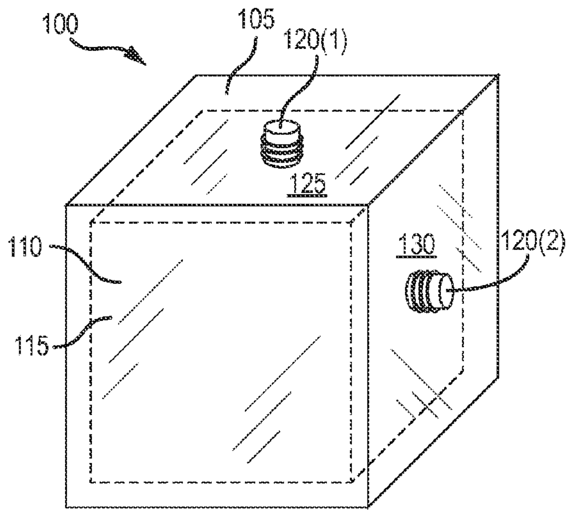


FIG. 1A

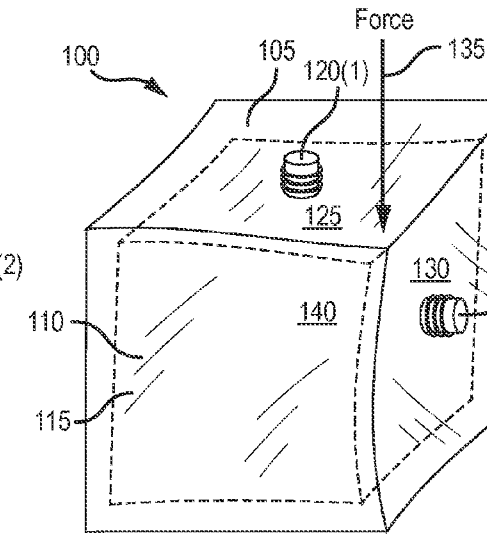


FIG. 1B

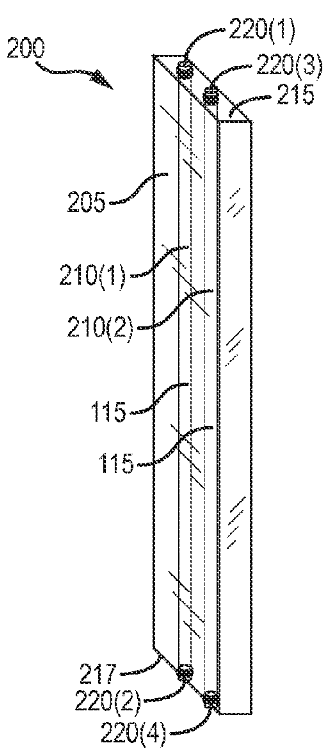


FIG. 2A

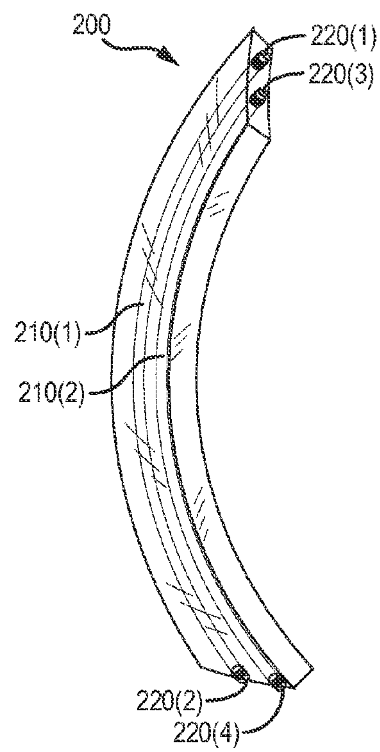


FIG. 2B

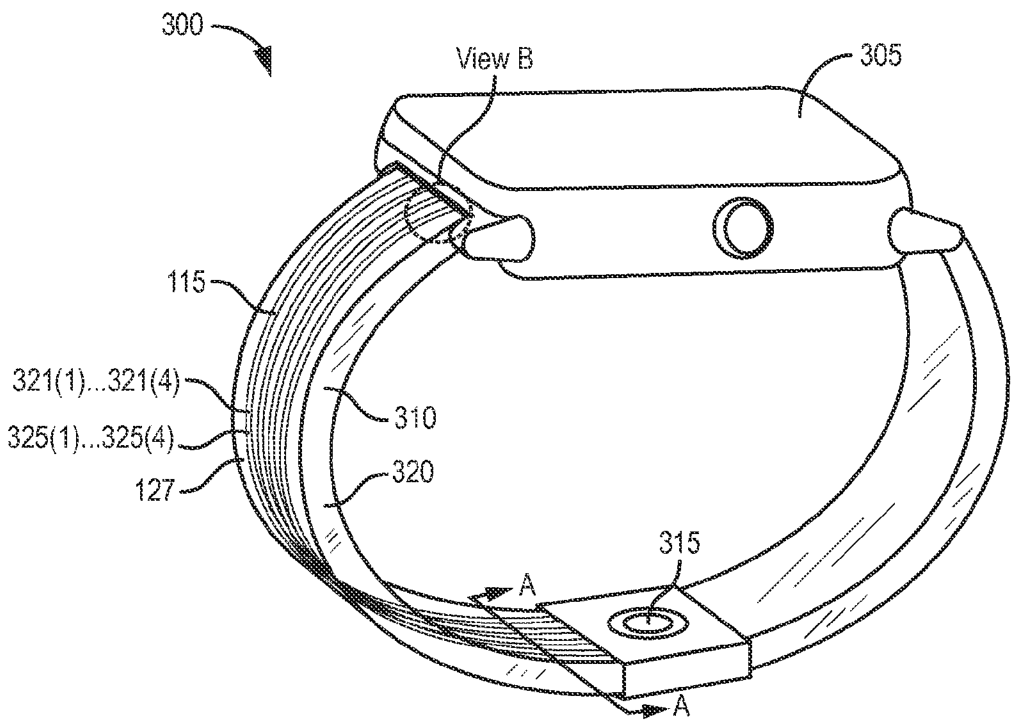


FIG. 3A

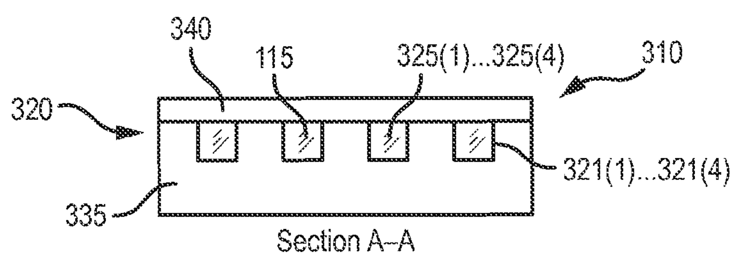


FIG. 3B

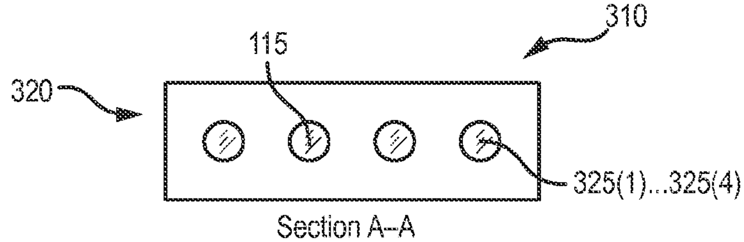


FIG. 3C

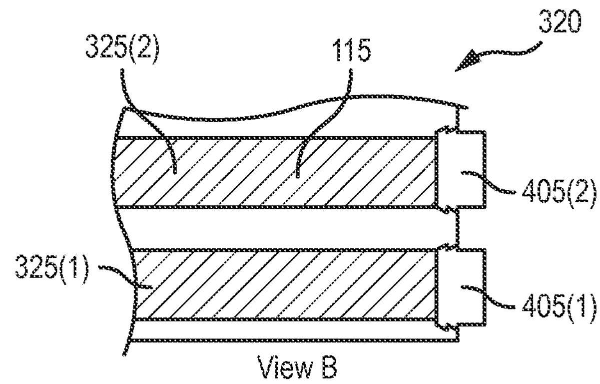

320
325(2)
115
405(2)
325(1)
405(1)
View B

FIG. 4

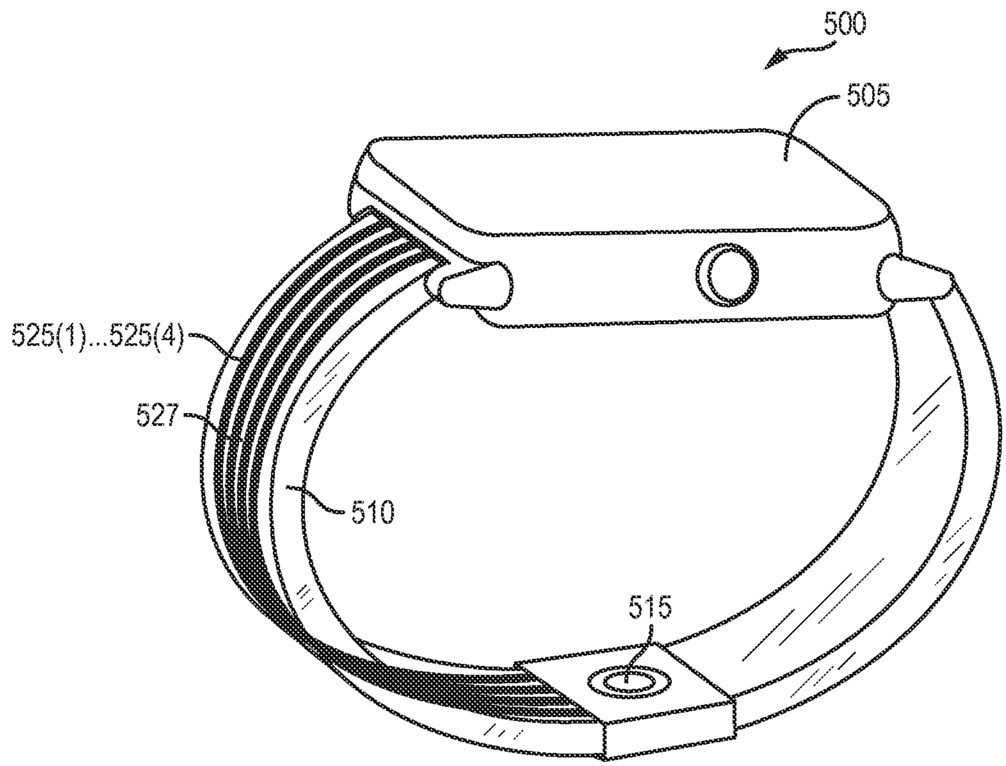

500
505
525(1)...525(4)
527
510
515

FIG. 5

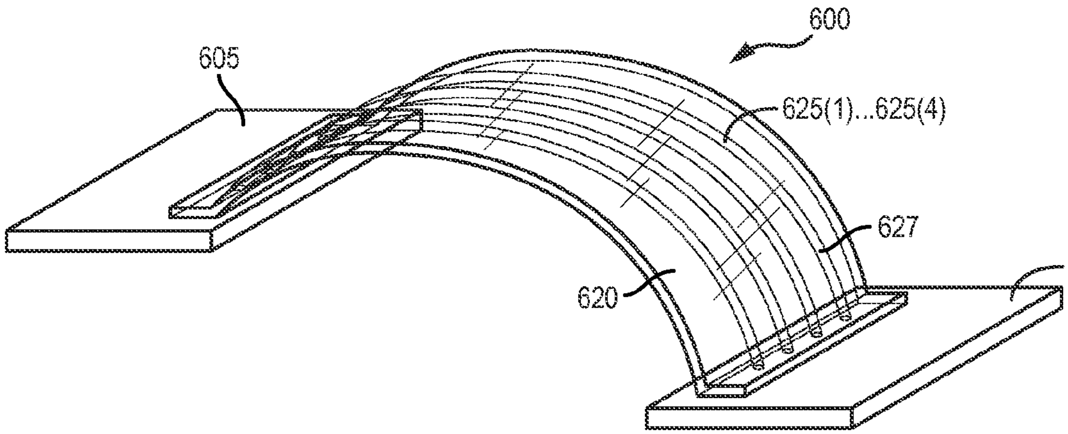


FIG. 6

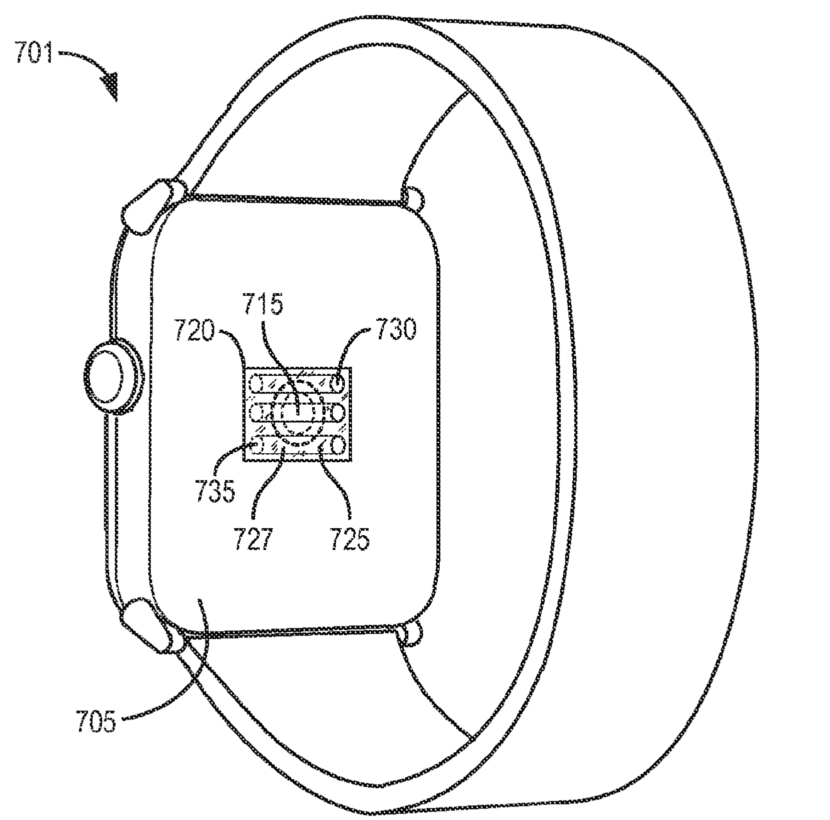


FIG. 7

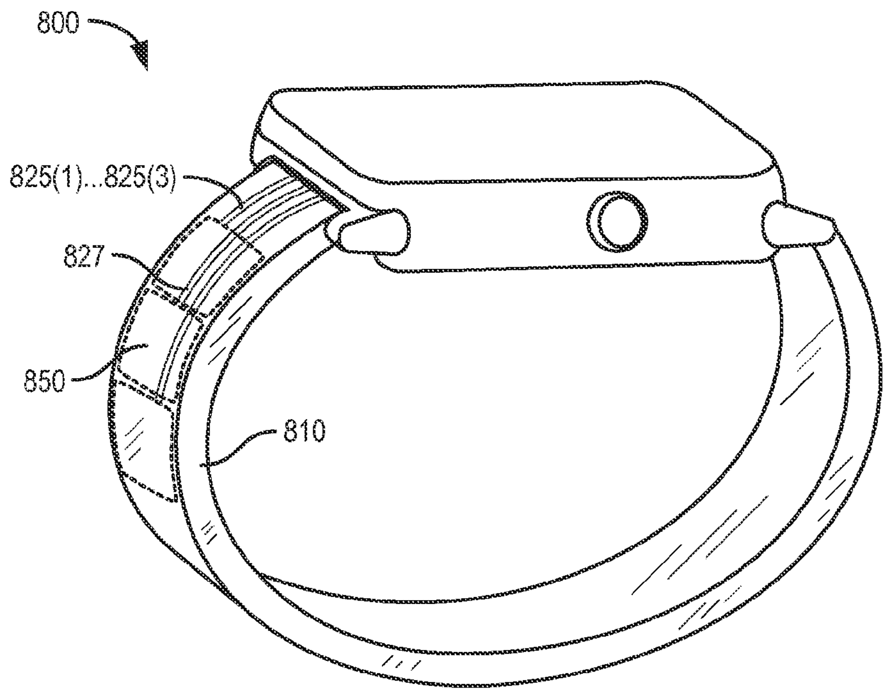


FIG. 8

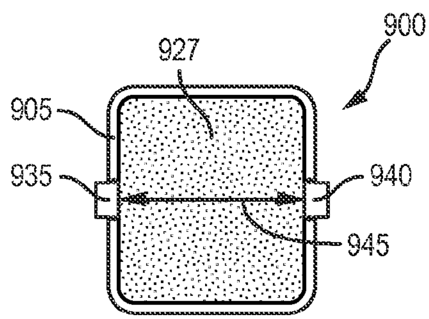


FIG. 9

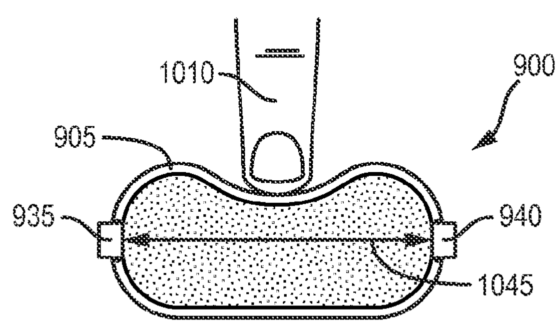


FIG. 10

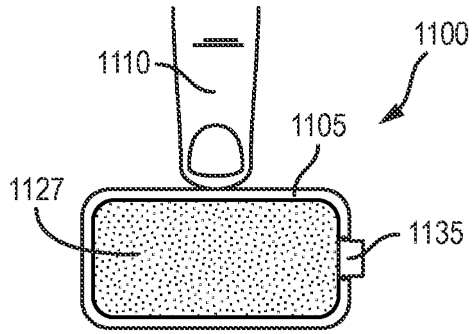


FIG. 11

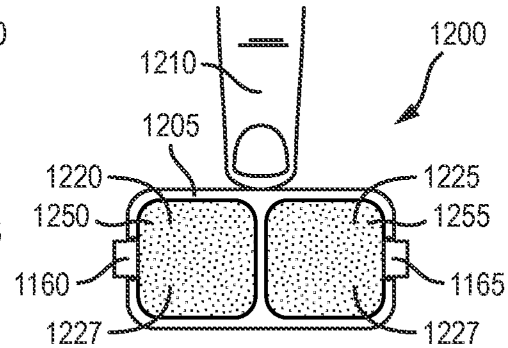


FIG. 12

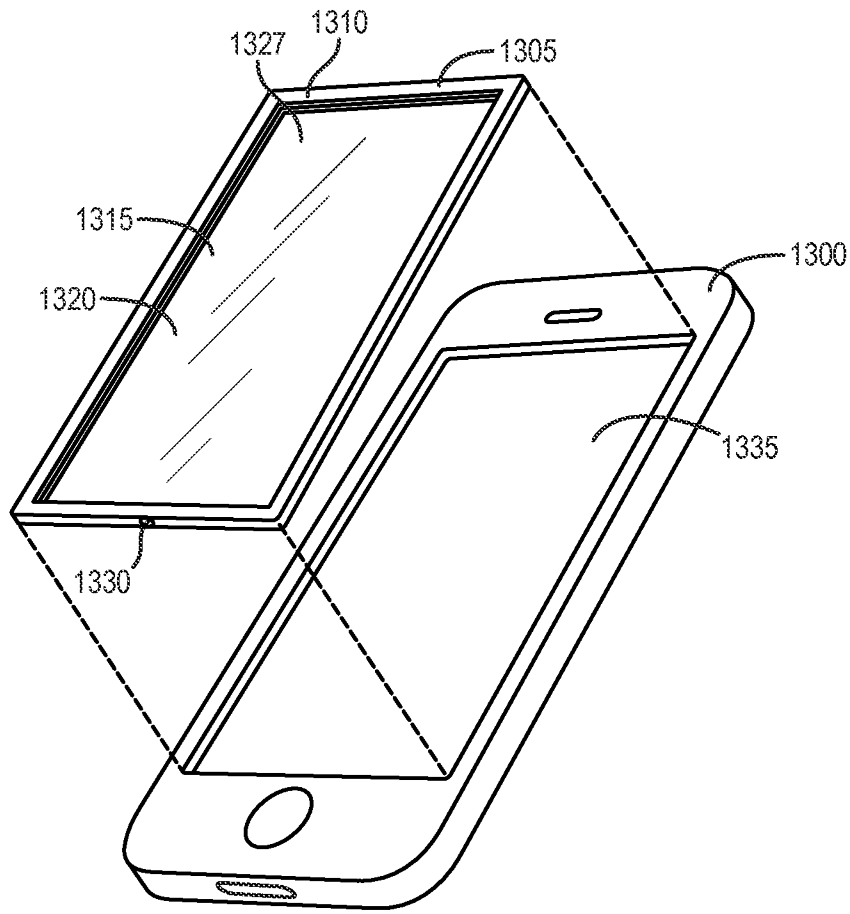


FIG. 13

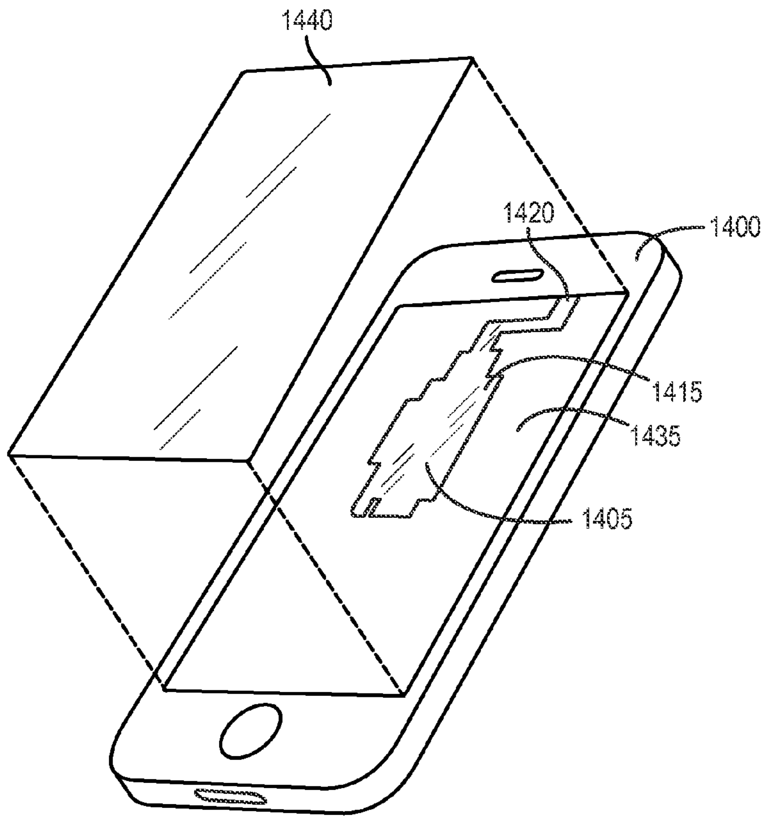


FIG. 14

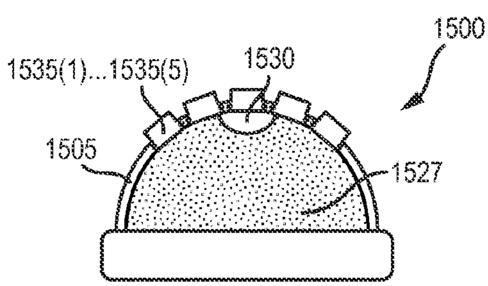


FIG. 15

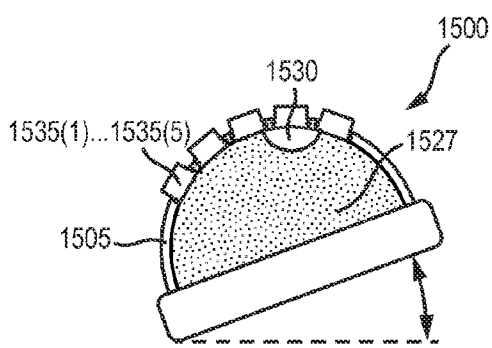
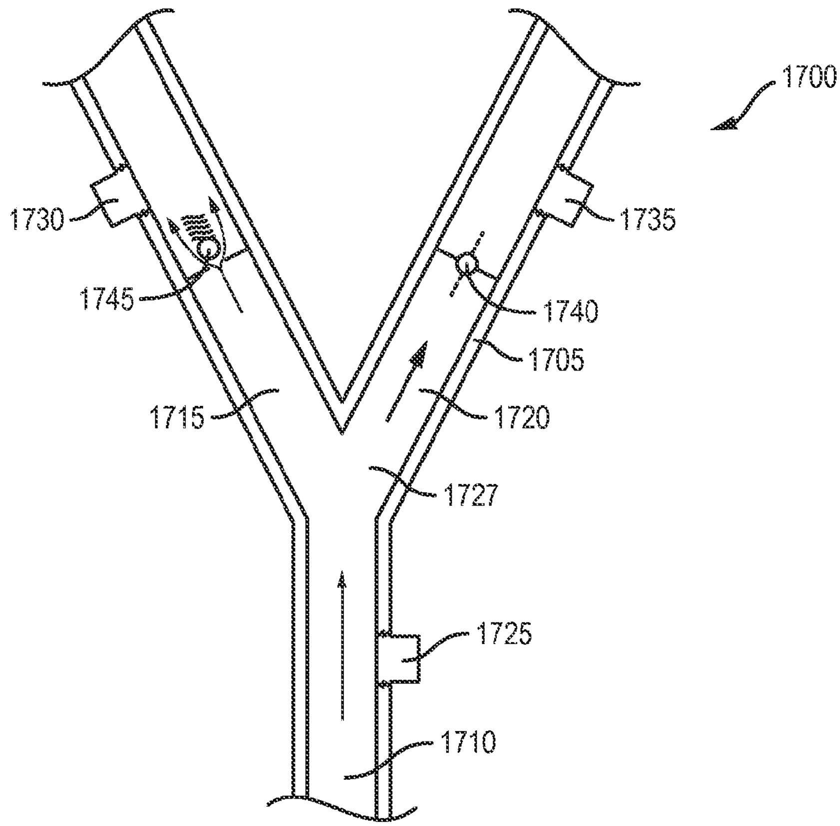


FIG. 16


1700
1730
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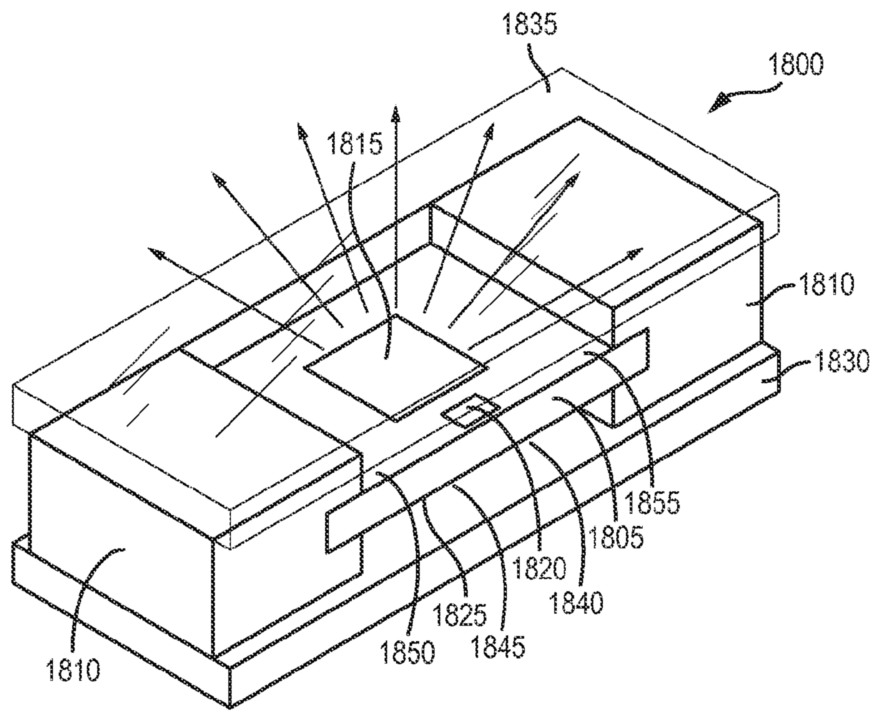
1710

FIG. 17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1800
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1810

FIG. 18

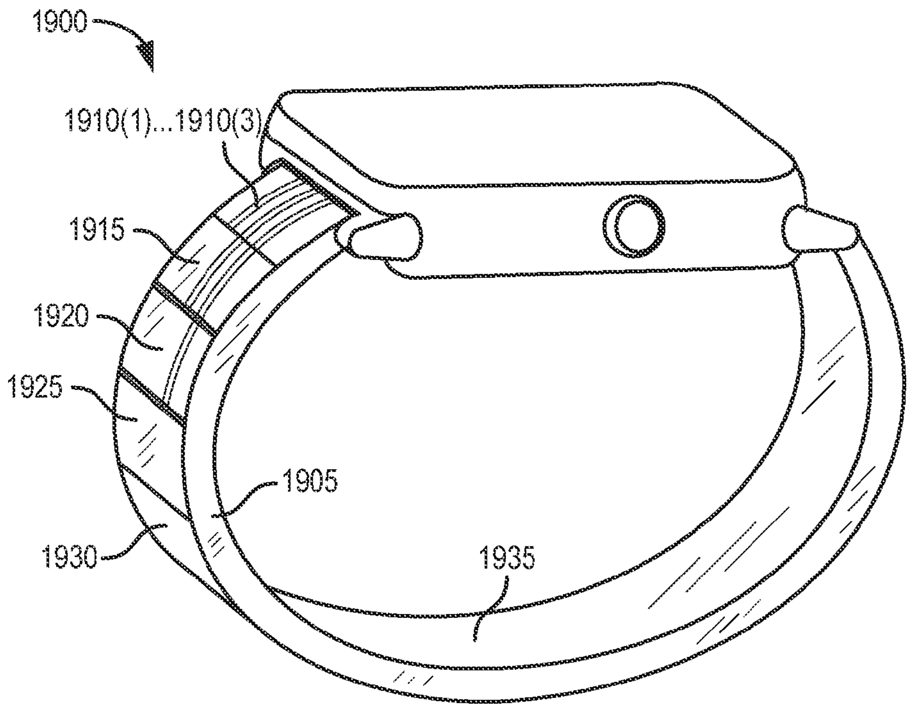
1900
1910(1)...1910(3)
1915
1920
1925
1905
1930
1935

FIG. 19

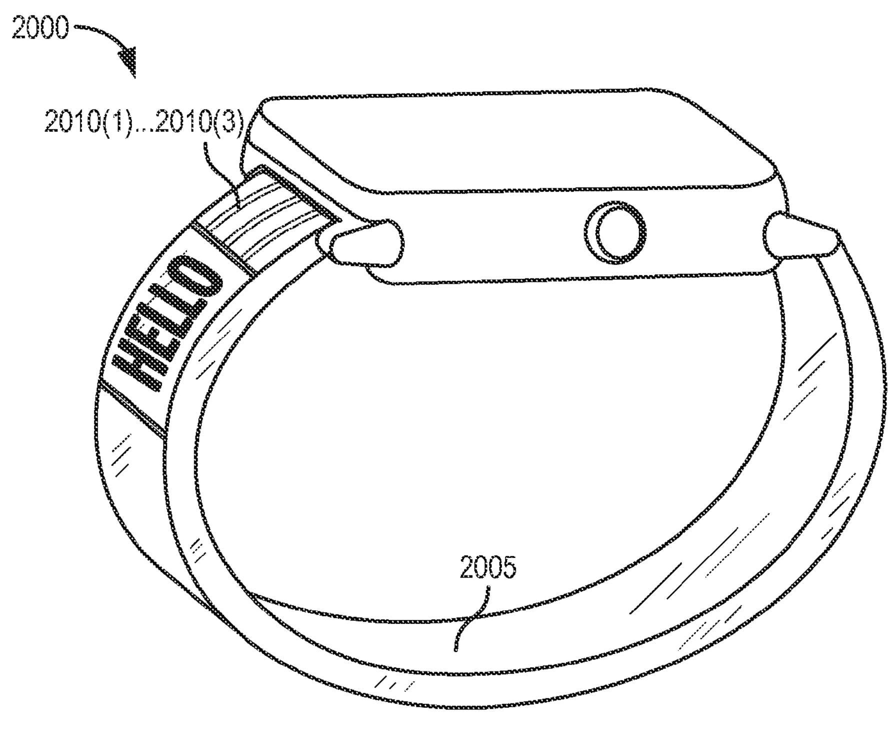
2000
2010(1)...2010(3)
HELLO
2005

FIG. 20

TRANSPARENT STRUCTURES FILLED WITH ELECTRICALLY ACTIVE FLUID

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to Provisional Application No. 62/134,195, filed Mar. 17, 2015, titled "TRANSPARENT STRUCTURES FILLED WITH ELECTRICALLY ACTIVE FLUID", which is hereby incorporated by reference in its entirety for all purposes.

FIELD

[0002] The described embodiments relate generally to three-dimensional optically transparent structures filled with an electrically active fluid. More particularly, the present embodiments relate to optically transparent structures that may be filled with an electrically conductive fluid or a fluid that changes crystalline structure under an applied voltage.

BACKGROUND

[0003] To meet the demands of consumers, electronic devices are required to be increasingly thin, lightweight and low cost with constantly increasing feature sets. Because of these demands, the packaging densities of electronic devices are increasing and the area available for interconnects, sensors and structures is being reduced. To meet the needs of future electronic devices new electronic structures and interconnects will be required.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] FIG. **1**A illustrates an isometric view of transparent deformable cube filled with a transparent electrically conductive fluid according to an embodiment of the invention;

[0005] FIG. **1**B illustrates an isometric view of the transparent deformable cube illustrated in FIG. **1**A in a deformed state according to an embodiment of the invention;

[0006] FIG. **2**A illustrates an isometric view of transparent deformable panel having two transparent electrically conductive channels according to an embodiment of the invention;

[0007] FIG. **2**B illustrates an isometric view of the transparent deformable panel illustrated in FIG. **2**A in a deformed state according to an embodiment of the invention;

[0008] FIG. **3**A illustrates an isometric view of a wearable device in accordance with an embodiment of the invention;

[0009] FIG. **3**B illustrates a cross-sectional view of the wearable device band shown in FIG. **3**A in accordance with an embodiment of the invention;

[0010] FIG. **3**C illustrates a cross-sectional view of the wearable device band shown in FIG. **3**A in accordance with an embodiment of the invention;

[0011] FIG. **4** illustrates a cross-sectional view of the wearable device band shown in FIG. **3**A in accordance with an embodiment of the invention;

[0012] FIG. **5** illustrates an isometric view of a wearable device in accordance with an embodiment of the invention;

[0013] FIG. **6** illustrates an isometric view of a flexible circuit in accordance with an embodiment of the invention;

[0014] FIG. **7** illustrates an isometric view of a wearable device with an integrated sensor in accordance with an embodiment of the invention;

[0015] FIG. **8** illustrates an isometric view of a wearable device with user input areas on the band in accordance with an embodiment of the invention;

[0016] FIG. **9** illustrates a cross-sectional view of a sensor in accordance with an embodiment of the invention;

[0017] FIG. **10** illustrates a cross-sectional view of the sensor illustrated in FIG. **9** being depressed by a finger in accordance with an embodiment of the invention;

[0018] FIG. **11** illustrates a cross-sectional view of a sensor in accordance with an embodiment of the invention;

[0019] FIG. **12** illustrates a cross-sectional view of the sensor illustrated in FIG. **11** being touched by a finger in accordance with an embodiment of the invention;

[0020] FIG. **13** illustrates an isometric view of an electronic device with a window in accordance with an embodiment of the invention;

[0021] FIG. **14** illustrates an isometric view of an electronic device with an antenna in accordance with an embodiment of the invention;

[0022] FIG. **15** illustrates a cross-sectional view of a sensor in accordance with an embodiment of the invention;

[0023] FIG. **16** illustrates a rotated cross-sectional view of the sensor shown in FIG. **15** in accordance with an embodiment of the invention;

[0024] FIG. **17** illustrates a cross-sectional view of a fluid flow channel in accordance with an embodiment of the invention;

[0025] FIG. **18** illustrates a partially transparent isometric view of an LED mount in accordance with an embodiment of the invention;

[0026] FIG. **19** illustrates an isometric view of a wearable device in accordance with an embodiment of the invention; and

[0027] FIG. **20** illustrates an isometric view of a wearable device in accordance with an embodiment of the invention.

DETAILED DESCRIPTION

[0028] Reference will now be made in detail to representative embodiments illustrated in the accompanying drawings. It should be understood that the following descriptions are not intended to limit the embodiments to one preferred embodiment. To the contrary, it is intended to cover alternatives, modifications, and equivalents as can be included within the spirit and scope of the described embodiments as defined by the appended claims.

[0029] Certain embodiments of the present invention relate to three-dimensional transparent structures filled with an electrically active fluid (e.g., a fluid that responds to an applied voltage by conducting current or changing crystalline structure). In some embodiments the electrically active fluid can be electrically conductive while also being transparent. The transparent fluid may be encased in a shell that is also transparent, enabling embodiments of the invention to provide optically transparent electrically conductive components. Such components may be useful in a variety of applications including optical sensors and aesthetically pleasing designs, as discussed in more detail below. In other embodiments the electrically conductive fluid may be opaque and employed in a flexible electrical interconnect structure having high mechanical fatigue performance. In yet further embodiments the electrically active fluid may change crystalline structure in response to an applied voltage, enabling a transparent component to change colors for aesthetic appeal. The foregoing embodiments are examples to illustrate some of the benefits of the invention; myriad other designs, geometries and configurations are possible and are within the scope of this disclosure. While the present invention can be useful for a wide variety of applications, some embodiments of the invention are particularly useful for electronic devices, as described in more detail below. The examples described below are only to illustrate the inventive concepts and in no way limit the applicability of the embodiments to alternatives, modifications, and equivalents.

[0030] Now referring to FIG. **1**A, an example embodiment of a three-dimensional transparent structure in the shape of a cube is shown. The cube may be made from a transparent flexible material and filled with a transparent electrically conductive fluid as described in greater detail below. Cube **100** may have an optically transparent shell **105** comprising six walls forming a cavity **110** therein. Shell **105** may be made from a flexible electrically insulating material as discussed in more detail below. Cavity **110** may be filled with an optically transparent electrically conductive fluid **115** as also discussed in more detail below. In other embodiments, electrically conductive fluid **115** may be translucent or opaque. A first electrically conductive plug **120**(**1**) may be disposed in a top wall **125** of shell **105** penetrating the electrically insulative shell and making electrical contact with electrically conductive fluid **115**. A second electrically conductive plug **120**(**2**) may be disposed in a first side wall **130** of shell **105**, penetrating the electrically insulative shell and making electrical contact with electrically conductive fluid **115**. Thus, electrical continuity may be formed between first and second electrically conductive plugs, **120**(**1**), **120**(**2**), respectively by forming a conductive path through electrically conductive fluid **115**.

[0031] Now referring to FIG. **1**B, cube **100** is illustrated in a deformed state caused by a force applied to a corner of the cube. During deformation from the geometry shown in FIG. **1**A to the geometry shown in FIG. **1**B, electrical continuity is maintained between first and second electrically conductive plugs **120**(**1**), **120**(**2**), respectively. More specifically, a force along arrow **135** has been place on a corner of cube **100** causing first and second side walls **130**, **140**, respectively, and top wall **125** to deform. As described above, in some embodiments shell **105** may be made from a flexible material, allowing cube **100** to deform. During the deformation, electrically conductive fluid **115** remains in contact with first and second electrically conductive plugs **120**(**1**), **120**(**2**), respectively, such that electrical continuity between the first and second plugs is maintained. Similarly, once the force is removed, electrical continuity between first and second electrically conductive plugs **120**(**1**), **120**(**2**), respectively, is maintained while cube **100** regains its original shape shown in FIG. **1**A. In an alternative embodiment, shell **105** may be made from a material that remains in the deformed state illustrated in FIG. **1**B after the force is removed. In this embodiment electrical conductivity may also be maintained between first and second electrically conductive plugs **120**(**1**), **120**(**2**), respectively.

[0032] Cube **100** is an embodiment illustrating a general concept. Alternatives, modifications, and equivalents are included within the spirit and scope this disclosure. For example, a modification of this concept may be useful for a touch sensor as illustrated in FIGS. **9-12**. Other embodiments may use alternative concepts for an electromagnetic interference shield as illustrated in FIG. **6** or a tilt sensor as illustrated in FIGS. **15-16**. Myriad other embodiments are possible and are within the scope of this disclosure.

[0033] Now referring to FIG. **2**A, another embodiment of a three-dimensional transparent structure filled with an electrically conductive fluid is illustrated. Panel **200** may have an optically transparent and elongated shell **205** that may be made from a flexible electrically insulating material. Shell **205** may have first and second elongated cavities **210**(**1**), **210**(**2**), respectively, formed within it and extending from a first end **215** of shell **205** to a second end **217** of the shell. A first electrically conductive plug **220**(**1**) may be secured in first end **215** of shell **205** and a second electrically conductive plug **220**(**2**) may be secured in second end **217** of the shell such that first elongated cavity **210**(**1**) is sealed. First elongated cavity **210**(**1**) may be filled with an optically transparent electrically conductive fluid **115** such that the fluid is in contact with first and second electrically conductive plugs **220**(**1**), **220**(**2**), respectively, forming an electrically conductive channel between the plugs.

[0034] Similarly, third and fourth electrically conductive plugs **220**(**3**), **220**(**4**), respectively may seal second elongated cavity **210**(**2**) that also contains optically transparent electrically conductive fluid **115**. Optically transparent electrically conductive fluid **115** may be in contact with third and fourth electrically conductive plugs **220**(**3**), **220**(**4**), respectively forming an electrically conductive channel between the third and fourth plugs. Therefore, elongated shell **205** may have two parallel and electrically isolated electrically conductive channels that extend from first end **215** to second end **217**.

[0035] Now referring to FIG. **2**B, panel **200** is illustrated in a deformed state. During deformation from the geometry shown in FIG. **2**A to the geometry shown in FIG. **2**B, electrical continuity is maintained between first and second electrically conductive plugs **220**(**1**), **220**(**2**), respectively and third and fourth electrically conductive plugs **220**(**3**), **220**(**4**), respectively. More specifically, panel **200** has been deflected from a relatively flat state shown in FIG. **2**A to an arcuate shape shown in FIG. **2**B. During and after the deformation, electrical continuity is maintained between first and second electrically conductive plugs **220**(**1**), **220**(**2**), respectively, and between third and fourth electrically conductive plugs, **220**(**3**), **220**(**4**), respectively. Thus, transparent and electrically conductive fluid **115** deforms with first and second elongated cavities **210**(**1**), **220**(**2**), respectively, such that electrical continuity is maintained when panel **200** is deformed.

[0036] Panel **200** is an embodiment illustrating a general concept. Alternatives, modifications, and equivalents are included within the spirit and scope this disclosure. For example, a modification of the concept may be useful for a watch band as illustrated in FIGS. **3**A-**5**. Other embodiments may employ alternative concepts for an antenna as illustrated in FIG. **14**. Myriad other embodiments are possible and are within the scope of this disclosure.

[0037] Now referring to FIG. **3**A, a wearable electronic device is shown that may incorporate one or more embodiments. The wearable device may have a substantially transparent band that provides electrical communication between the wearable device display and a user pulse sensor located on a distal portion of the band. The communication may be performed using one or more transparent elongated cavities in the band that are filled with a transparent electrically conductive fluid forming one or more electrically conductive channels. The transparent band with electrically conductive channels may provide the wearable device with an aesthetically appealing design and improved mechanical fatigue performance, as described in more detail below.

[0038] More specifically, wearable device **300** may have a display portion **305** that may contain a display screen, a processor and other electronic components (not shown). Display portion **305** may be connected to a transparent band **310** such that wearable device **300** can be secured to a user's wrist. A sensor **315** may be located on a distal portion of band **310** and used to sense the user's pulse, for example. In one embodiment, band **310** may be a flexible three-dimensional substantially transparent structure having an optically transparent shell **320** with multiple elongated cavities **321(1)** . . . **321(4)** disposed within it. Elongated cavities **321(1)** . . . **321(4)** may be filled with a transparent electrically conductive fluid, **115** forming one or more electrically conductive channels **325(1)** . . . **325(4)** as described in more detail below. Electrically conductive channels **325(1)** . . . **325(4)** may be used by display portion **305** to communicate with sensor **315**. In the embodiment illustrated in FIG. **3**A, four conductive channels **325(1)** . . . **325(4)** are depicted, however other embodiments may have fewer or more conductive channels. Shell **320** may be made from a rigid, a semi-rigid or a flexible material. Thus, band **310** may be substantially transparent providing an aesthetically appealing appearance while providing electrical communication between display portion **305** and sensor **315**. Further, since conductive channels **325(1)** . . . **325(4)** are filled with a fluid, band **310** may have substantially improved mechanical fatigue performance as compared to a band with metallic wire conductors that are subject to fatigue failure.

[0039] Now referring to FIG. **3**B, section A-A of band **310** (see FIG. **3**A) is illustrated. In one embodiment, shell **320** may include a base portion **335** having elongated cavities **321(1)** . . . **321(4)** formed along a length of band **310**. Elongated cavities **321(1)** . . . **321(4)** may be formed, for example, during a molding or an extruding process. As discussed above, elongated cavities **321(1)** . . . **321(4)** may be filled with transparent electrically conductive fluid **115**. A cover **340** may be secured to base portion **335** such that transparent electrically conductive fluid **115** is contained within elongated cavities **321(1)** . . . **321(4)** forming conductive channels **325(1)** . . . **325(4)**. Transparent electrically conductive fluid **115** may be disposed within elongated cavities **321(1)** . . . **321(4)** prior to securing cover **340** or after securing the cover. Cover **340** may be secured to base portion **335** using, for example, an adhesive, bonding, fusing or welding process. In this embodiment, conductive channels **325(1)** . . . **325(4)** may have a rectangular cross-section as shown in FIG. **3**B. However, in other embodiments conductive channels **325(1)** . . . **325(4)** may have a different cross-section and may be manufactured using an alternative process.

[0040] Now referring to FIG. **3**C, another embodiment of section A-A through band **310** (see FIG. **3**A) is illustrated. In this embodiment conductive channels **325(1)** . . . **325(4)** have a circular cross section and shell **320** may be substantially unitary. As described above, conductive channels **325(1)** . . . **325(4)** may be filled with a transparent electrically conductive fluid **115**. Transparent electrically conductive fluid **115** may be disposed within conductive channels **325(1)** . . . **325(4)** during the manufacturing of shell **320** or after it is manufactured. For example, transparent electrically conductive fluid **115** may be deposited during extrusion molding of shell **320**, or the fluid may be disposed within the conductive channels after they are formed in the shell.

[0041] Now referring to FIG. **4**, an enlargement of View-B of shell **320** in FIG. **3**A is shown. As discussed above, conductive channels **325(1)**, **325(2)** are filled with a transparent electrically conductive fluid **115**. Electrically conductive plugs **405(1)**, **405(2)** may be disposed within conductive channels **325(1)**, **325(2)** and configured to make electrical contact with transparent electrically conductive fluid **115**. In some embodiments, electrically conductive plugs **405(1)**, **405(2)** may be disposed in both distal ends of conductive channels **325(1)**, **325(2)** such that transparent electrically conductive fluid **115** is contained within the channels and electrical contact may be made from one end of band **310** (see FIG. **1**) to the other end through the fluid. That is, a combination of two conductive plugs disposed on either end of a conductive channel **325(1)**, **325(2)** may form a continuous electrical conductor similar in function to a metallic wire and as shown earlier in FIGS. **2**A-**2**B. Electrically conductive plugs **405(1)**, **405(2)** may be secured within conductive channels **325(1)**, **325(2)** with a press-fit, bonding, welding or fusing process. Electrically conductive plugs **405(1)**, **405(2)** may then be electrically coupled to wearable device display portion **305** (see FIG. **3**A) and/or sensor **315** forming a complete electrical circuit between the display and the sensor. In some embodiments, electrically conductive plugs **405(1)**, **405(2)** may form a portion of an electronic connector that is coupled to band **310**.

[0042] The combination of transparent shell **320** and transparent electrically conductive fluid **115** may provide band **310** (see FIG. **3**A) with a substantially transparent and aesthetically pleasing appearance. In further embodiments, where shell **320** is made from a relatively soft material, band **310** (see FIG. **3**A) may be able to withstand many cycles of deflection, such as when the band is secured to the user's wrist. Because the electrical conductors within band **310** are made with a fluid, and not a metallic wire, they are not subject to mechanical fatigue and fracture like the wire.

[0043] In further embodiments shell **320** may be made from an optically transparent and relatively rigid material such as, for example, polycarbonate or glass. Rigid embodiments may have a hardness from Shore A 100 to Shore D 100 and harder. In other embodiments conductive shell **320** may be made from an optically transparent semi-rigid material such as, for example, transparent nylon. Some semi-rigid embodiments may have a hardness from Shore A 40 to Shore A 100. In further embodiments shell **320** may be made from a flexible material such as, for example, a transparent silicone or an elastomer. Some flexible embodiments may have a hardness from a Shore 00 10 to Shore A 40. Further embodiments may have a hardness from Shore A 0 to Shore A 100. Myriad optically transparent or translucent materials may be used for shell **320** without departing from the invention. In some embodiments, shell **320** may be formed by injection molding, blow molding, casting or three-dimensional printing. Myriad materials and manufacturing methods may be used to form shell **320** and are within the scope of this disclosure.

[0044] In some embodiments, electrically conductive plugs **405(1)**, **405(2)** may be made from an electrically conductive metal such as brass, copper, stainless steel or other metal. In other embodiments electrically conductive plugs **405(1)**, **405(2)** may be made from an electrically conductive plastic such as, for example conductive nylon. In further embodiments electrically conductive plugs **405(1)**, **405(2)** may be plated with one or more metals such as, for example, nickel, copper, gold, silver, palladium or other metal. In one embodiment, electrically conductive plugs **405(1)**, **405(2)** may be made from a non-electrically conductive plastic that may be plated with one or more metals.

[0045] In further embodiments transparent electrically conductive fluid **115** may comprise water with one or more ionic compounds dissolved in it such as a salt or other compound making it electrically conductive. In yet further embodiments transparent electrically conductive fluid **115** may comprise tin-oxide that may be doped with antimony or phosphorous. In other embodiments transparent electrically conductive fluid **115** may be translucent or opaque, as in the embodiment below, comprising a metal or alloy such as for example, mercury. In other embodiments transparent electrically conductive fluid **115** may be what is known as an electrically conductive ink, or a liquid carrier filled with one or more types of electrically conductive particulates. Myriad electrically conductive fluids may be used and are within the scope of this disclosure.

[0046] Now referring to FIG. **5**, wearable device **500** may be similar to wearable device **300** illustrated in FIG. **3**A, however wearable device **500** may employ an optically translucent or opaque electrically conductive fluid in the band as compared to wearable device **300** that employed an optically transparent electrically conductive fluid. Thus, wearable device **500** may have a band that is resilient to mechanical fatigue with visible conductive channels.

[0047] More specifically, wearable device **500** may have a display portion **505** that may be connected to a transparent band **510** such that wearable device **500** can be secured to a user's wrist. A sensor **515** may be located on a distal portion of band **510** and used to sense the user's pulse, for example. Band **510** may be a flexible three-dimensional substantially transparent structure having multiple electrically conductive channels **525**(**1**) . . . **525**(**4**) disposed within it. Electrically conductive channels **525**(**1**) . . . **525**(**4**) may be filled with a translucent or opaque electrically conductive fluid, **527** as described in more detail above. Electrically conductive channels **525**(**1**) . . . **525**(**4**) may be used by display portion **505** to communicate with sensor **515**, or they may be used for other functions as described in more detail below.

[0048] Now referring to FIG. **6**, a three-dimensional flexible electrical interconnect structure **600** that is similar to bands **310**, **510** (see FIGS. **1** and **5**) is illustrated. However, instead of being used as a wearable device band, structure **600** may be used to interconnect electronic components **605**, **610**. For example, in one embodiment structure **600** may be used to electrically interconnect two printed circuit boards **605**, **610**. Structure **600** may function similar to a flexible printed circuit board, however structure **600** uses fluid filled electrically conductive channels instead of metallic conductors such that it has high mechanical fatigue properties and/or is substantially transparent for aesthetic appeal.

[0049] More specifically, structure **600** may include a three-dimensional flexible shell **620** that may have multiple electrically conductive channels **625**(**1**) . . . **625**(**4**). Shell **620** may be manufactured from a material that is semi-rigid or flexible to allow it to deform without breaking, as discussed above. In one embodiment electrically conductive channels **625**(**1**) . . . **625**(**4**) may be filled with an electrically conductive fluid **627**. In some embodiments fluid **627** may be opaque, while in other embodiments it may be translucent and in further embodiments is may be transparent. In some embodiments, a substantially transparent structure **600** (i.e., one that employs a translucent or transparent fluid **627**) may be beneficial for applications requiring aesthetic appeal such as electronic devices, toys and games. Such applications may use structure **600** entirely for its aesthetic appeal (e.g., a computer with a viewing window showing the internal components where structure **600** is used to minimally obscure one's view) or for functional purposes (e.g., an LCD screen is illuminated through structure **600**). Structure **600** may be manufactured using similar processes as discussed above. Such embodiments may have the benefit of being optically transparent and surviving many cycles of bending without fatigue damage since the conductors are composed of electrically conductive fluid. In further embodiments transparent structure **600** may conduct electrical signals in multiple dimensions instead of being limited to planar two-dimensional structures like flexible circuit boards.

[0050] Now referring to FIG. **7**, according to another embodiment of the invention, a transparent window with transparent electrical conductors may be used in the back of a wearable device such that an optical sensor can transmit and receive optical signals through the window and the conductors. More specifically, wearable device **701** may have a display portion **705** with an optical sensor **715** disposed within it. Optical sensor **715** may emit and/or receive a light beam through a transparent structure **720**. For example, sensor **715** may be disposed within display portion **705** of wearable device **701** and transmit and receive light through structure **720** to determine a user's pulse. In some embodiments, structure **720** may not only act as a window, but may also function as an electrical connector from the outside of wearable device **701** to the inside of the wearable device. Structure **720** may have multiple external electrical contacts **730** that are accessible from the outside of wearable device **701**. External electrical contacts **730** may be electrically coupled to internal contacts **735** by transparent electrically conductive channels **725**. Transparent electrically conductive channels **725** may be filled with transparent electrically conductive fluid **727** providing electrical continuity between external electrical contacts **730** and internal electrical contacts **735**. In some embodiments, transparent electrically conductive fluid **727** may be transparent only within the bandwidth of sensor **715** such that the sensor **715** may emit and/or receive light through transparent structure **720**. More specifically, the combination of structure **720** being made from a transparent material and fluid **727** being transparent enables sensor **715** to transmit and receive light through the window which contains conductive channels **725**.

[0051] Referring now to FIGS. **8-12**, some embodiments may form user input devices such as touch sensitive "buttons" on a wearable device band or other electronic device. The user input devices may be employed by a user to change a state of the device, such as, for example answering a call, pausing a video or muting an alarm on a wearable device. In some embodiments employed on a wearable device, the user input devices as well as the wearable device band they are disposed on may be substantially transparent giving the wearable device aesthetic appeal. Transparent conductors, as discussed above, may be used to communicate with the user input devices to provide further aesthetic appeal. For example, in one embodiment the entire wearable device band may be substantially transparent, however when a user touches a region of the band near the display the wearable device may change states in response. Other user inputs may also be recognized such as a user sliding their finger along a portion of the band. The embodiments illustrated in FIGS. **8-12** may be manufactured using similar methods as those illustrated above, having a shell filled with an electrically conductive fluid that may be in contact with one or more electrically conductive plugs. User input devices may detect user input using pressure, capacitive or other types of sensing. In some embodiments the user input devices may employ an opaque fluid and be mostly visible, while in other embodiments they may employ a translucent or transparent fluid and be substantially transparent, except for the conductive plugs.

[0052] Now referring to FIG. **8**, in one embodiment one or more user input devices **850** may be disposed on band **810** of wearable device **800**. The user input device may be a region on the wearable device band that a user can lightly touch, or firmly depress to control the wearable device. In some embodiments the user input device may use a transparent electrically conductive fluid and be substantially transparent for aesthetic appeal. For example, user input devices **850** may enable a user to answer a call, to stop playing music or to show the current time by simply touching or depressing a particular region on the wearable device band. Other embodiments may have more or less user inputs and they may be used for myriad functions. Similar to embodiments discussed above, some user input devices may be visible while others may be translucent or mostly transparent. In one embodiment an optically transparent band **810** may be used with an optically transparent or translucent fluid to provide an aesthetically pleasing appearance to wearable device **800**.

[0053] Wearable device **800** may be similar to wearable device **500** shown in FIG. **5** and have multiple conductive channels **825(1)** . . . **825(3)** filled with electrically conductive fluid **827** disposed within transparent band **810**. However, in this embodiment, conductive channels **825(1)** . . . **825(3)** may be used to provide electrical connections to one or more transparent or semi-transparent input devices **850**. Myriad methods may be used to make input devices **850**. In one embodiment input devices **850** may be configured to detect a user's touch by a change in electrical resistance or mutual capacitance, as described in more detail below.

[0054] Now referring to FIGS. **9** and **10**, a cross-section of an embodiment of a resistive-type user input device **900** is illustrated. FIG. **9** illustrates the user input device before being depressed and FIG. **10** illustrates the user input device after being depressed. An arrow is used to illustrate the increase in distance between two conductive plugs when the device is depressed by a user's finger. This illustration is an example and other geometries and configurations are within the scope of this disclosure. Such devices can be readily integrated by those of skill in the art into wearable device band **810** as illustrated in FIG. **8**, or in any other device.

[0055] User input device **900** may be made from a flexible or semi-flexible transparent or translucent material as discussed above. Wall **905** may form a continuous enclosure that contains electrically conductive fluid **927**. Wall **905** may have electrically conductive plugs **935**, **940** configured to form an electrical connection to fluid **927**. Plugs **935**, **940** may be a first distance **945** apart, with only fluid **927** forming an electrical connection between them.

[0056] Now referring to FIG. **10**, user input device **900** is illustrated in a deformed state, such as, for example when a user's finger **1010** depresses it. Wall **905** has deformed causing plugs **935**, **940** to move apart to a second distance **1045** that is greater than first distance **945** (see FIG. **9**). The greater distance between plugs **935**, **940** causes the electrical resistance between the plugs to increase. The increase in resistance may be used to sense a user's touch on input device **900**. In some embodiments the change in electrical resistance may be amplified and determined by the use of a Wheatstone bridge or other circuit. Thus, in some embodiments not only the depression of input device **900** may be determined, but the amount of depression and/or the applied force may be determined.

[0057] The deformation and distances **945**, **1045** are exaggerated in FIGS. **9** and **10**, thus much smaller changes in distance may be used. Other configurations are within the scope of this disclosure such as, but not limited to placing one plug **935** on the surface which the user depresses and placing the other plug **940** on the opposite wall. Myriad methods of making such an input device are within the scope of this disclosure. As discussed in more detail above, fluid **927** may be transparent, semi-transparent or opaque. Such methods may be used to form a substantially transparent or semi-transparent user input device where only plugs **935**, **940** may be visible or opaque.

[0058] Referring now to FIG. **11**, other embodiments may form a transparent capacitive-type user input device **1100**. In one embodiment, a self or absolute capacitance type sensor may be formed where an object (e.g., a finger **1110** or a stylus) capacitively loads device **1100** or increases the parasitic capacitance to ground. In one embodiment, wall **1105** may form a continuous enclosure that contains electrically conductive fluid **1127**. Wall **1105** may have electrically conductive plug **1135** configured to form an electrical connection to fluid **1127**. Electrically conductive plug **1135** may be configured to make electrical contact with electrically conductive fluid **1127** such that the electrically conductive fluid may act as a sensor to detect user's **1110** touch on device **1100**. As discussed in more detail above, fluid **1127** may be transparent, semi-transparent or opaque.

[0059] Now referring to FIG. **12**, in other embodiments a mutual capacitance type of input device **1200** may be formed. Input device **1200** is similar to input device **1100** illustrated in FIG. **11**, however input device **1200** monitors mutual coupling between two adjacent electrodes, as discussed in more detail below. A user's interaction with input device **1200** is indicated by detecting a change in mutual capacitance between the two electrodes. In the embodiment illustrated in FIG. **12**, an object (e.g., finger **1210** or conductive stylus) alters the mutual coupling between two or more electrodes **1220**, **1225**, which may be scanned sequentially. In one embodiment, wall **1205** may form a first continuous enclosure **1250** and a separate second continuous enclosure **1255**, each enclosure containing electrically conductive fluid **1227**. First and second enclosures **1250**, **1255**, respectively, filled with fluid **1227** may form electrodes **1220**, **1225**. First and second enclosures **1250**, **1255**, respectively, may each have an electrically conductive plug **1160**, **1165**, respectively, configured to form an electrical connection to fluid **1227**. As discussed in more detail above, fluid **1227** may be transparent, semi-transparent or opaque.

[0060] Now referring to FIG. **13**, an embodiment employing a transparent electrically conductive fluid may be employed as a transparent electromagnetic interference (EMI) shield in an electronic device **1300**. The transparent EMI shield may allow it to be used over a display without obscuring the display like other types of EMI shields. Although electronic device **1300** is illustrated as a phone, the electronic device may be any type of device such as a laptop computer, a computer monitor, a camera or other device. In this embodiment, a three-dimensional transparent structure **1305** may be used as an EMI shield to protect electronic device **1300** from externally generated EMI and may also be used to keep internally generated EMI within the electronic device.

[0061] In some embodiments, structure **1305** may be made from a frame **1310** and a pair of transparent windows **1315**, **1320**. In some embodiments transparent windows **1315**, **1320** may be made from one or more of the materials discussed above including, but not limited to, transparent polycarbonate or glass. Transparent windows **1315**, **1320** and frame **1310** may form a substantially enclosed structure containing a transparent electrically conductive fluid **1327**. Transparent electrically conductive fluid **1327** may be electrically connected to a ground through one or more conductive plugs **1330**. Fluid **1327** may form a transparent EMI shield, effectively attenuating impinging electromagnetic energy. The thickness of the fluid, the electrical conductivity of the fluid and the type of fluid, among other parameters, may be varied to achieve effective EMI shielding while maintaining optical transparency.

[0062] In some embodiments, structure **1305** may be employed over a display screen **1335** on electronic device **1300**, thus providing the ability for a user to view the display screen through the EMI shield. In other embodiments, structure **1305** may be employed over other electronic device elements such as, but not limited to, optical sensors, cameras, lights and internal components. Myriad other uses and configurations for structure **1305** are within the scope of this disclosure. For example, structure **1305** may not be two-dimensional and may be three-dimensional covering a curved display screen or other non-two-dimensional structure.

[0063] Now referring to FIG. **14**, an embodiment may be employed as an antenna in an electronic device **1400**. The antenna may be transparent, enabling it to be placed in front of a display screen without obscuring the user's view of the screen. Although electronic device **1400** is illustrated as a phone, the electronic device may be any type of device such as a laptop computer, a computer monitor, a camera or other device. In this embodiment, a three-dimensional transparent structure **1405** may be used as an antenna to transmit or receive information. Such antennas may be used to transmit and receive data on cellular, WiFi, Bluetooth or other bands.

[0064] In one embodiment, transparent structure **1415** may form a substantially enclosed cavity containing a transparent electrically conductive fluid **1427**. Transparent structure **1415** may be made from a transparent material such as, for example, polycarbonate, silicone, acrylic, vinyl or myriad other films. Fluid **1427** may be electrically connected to an antenna circuit through one or more conductive interconnects **1420** such that it forms a transparent antenna. Conductive interconnect **1420** may be formed as discussed above using an electrically conductive plug or other method. The pattern of fluid **1427**, the thickness of the fluid, the electrical conductivity of the fluid and the type of fluid, among other parameters, may be varied to achieve an effective antenna gain while maintaining optical transparency.

[0065] In some embodiments, structure **1415** may be employed over a display screen **1435** on electronic device **1400**, thus providing the ability for a user to view the display screen through the antenna. In further embodiments a transparent protective screen **1440** may be placed over structure **1415** and display screen **1435**. In other embodiments, structure **1405** may be employed over other electronic device elements such as, but not limited to, optical sensors, cameras and lights. Myriad other uses and configurations for structure **1405** are within the scope of this disclosure. For example, structure **1405** may not be two-dimensional and may be three-dimensional and placed on a curved display screen or other non-two-dimensional structure.

[0066] Now referring to FIG. **15**, an embodiment may function as an orientation or gravitational force sensor **1500**. A device may be filled with an electrically conductive liquid and based on the location of a bubble in the liquid electrical connections to conductive plugs may be made or broken, indicating a change in state or position of the sensor. Such a sensor may be used in myriad applications such as within an electronic device, a toy, an automobile or any other device that benefits from information on orientation and changes in gravitational force.

[0067] A simplified cross-section of one embodiment is illustrated in a first position in FIG. **15**. Sensor **1500** may have a wall **1505** forming a substantially continuous enclosure that contains electrically conductive fluid **1527** containing a void **1530** disposed within the fluid. Wall **1530** may have one or more electrically conductive plugs **1535(1)** . . . **1535(5)** configured to form an electrical connection to fluid **1527**. This embodiment has five conductive plugs **1535(1)** . . . **1535(5)** in a row, however other embodiments may have fewer or more and they may be in multiple rows, orientations and directions.

[0068] Wall **1505** may be made from an electrically insulative material. Conductive plugs **1535(1)** . . . **1535(5)** may be configured to make electrical contact with electrically conductive fluid **1527** or to be isolated from the fluid by void **1530** such that an orientation of sensor **1500** may be determined. More specifically, in some embodiments multiple conductive plugs **1535(1)** . . . **1535(5)** may be used, and by sensing which plugs are in contact with fluid **1527** and which are not, the orientation of sensor **1500** may be determined. For example, FIG. **16** illustrates sensor **1500** in a different orientation where void **1530** has moved and a different conductive plug **1535(1)** . . . **1535(5)** is electrically isolated from fluid **1527**. As illustrated, void **1530** may change location based on an orientation of sensor **1500**, however void may also change location based on the centrifugal force or magnetic field that sensor **1500** is exposed to. In particular, if fluid **1527** is magnetic, void **1530** would change location based on the location of an applied magnetic field to sensor **1500**.

[0069] In some embodiments wall **1505** may be made from a transparent material while in other embodiments it may be made from a semi-transparent or an opaque material. In further embodiments fluid **1527** may be made from a transparent material while in other embodiments it may be made from a semi-transparent or an opaque material. In some embodiments a substantially transparent sensor **1500** may be beneficial such as in an application that must pass light through sensor **1500**.

[0070] Now referring to FIG. **17**, in one embodiment a channel structure **1700** may be filled with an electrically conductive fluid **1727** and be employed as a flow sensor and/or a fluid flow logic device, as described in more detail below. Structure **1700** may have one or more walls **1705** forming one or more channels **1710**, **1715**, **1720** configured to allow fluid **1723** to flow through them. Walls **1705** may have multiple electrically conductive plugs **1725**, **1730**, **1735** disposed within them. Plugs **1725**, **1730**, **1735** may make electrical contact with fluid **1727** and be used as feedback, as discussed as more detail below.

[0071] In some embodiments plugs **1725**, **1735** may be disposed in side wall **1705** of channels **1710**, **1720**, respectively. Plugs **1725**, **1735** may be configured to make electrical contact with fluid **1727**. An electrically insulative valve **1740** may be placed in channel **1720** and configured such that in a first position fluid **1727** may flow past the valve and in a second position the valve may stop the flow of fluid and electrically isolate upstream fluid from downstream fluid. That is, when valve **1740** is in a closed position there may be little to no electrical continuity between plugs **1725** and **1735**, however when the valve is open, continuity is restored. Thus, such a system can be used to create or break continuity between plugs **1725**, **1735** as well as block the flow of fluid **1727**.

[0072] In another embodiment, a check valve **1745** may be employed in channel **1715**. Check valve **1745** may electrically isolate plug **1730** from plug **1725** and **1735** when in a closed position. However when in an open position, electrical continuity is restored between plugs **1725**, **1730** and **1735**. In one example embodiment, channel **1727** may run through a filter or other device and when the pressure required to get through the filter increases beyond the pressure required for check valve **1745** to open, the check valve opens. The open check valve allows electrically conductive fluid **1727** to flow past plug **1730** creating electrical continuity between plugs **1725**, **1730** and **1735**.

[0073] In further embodiments, an electrical logic system may be used to detect continuity between plugs **1725**, **1730** and **1735** and notify an operator that check valve **1745** has opened. In another illustrative example, check valve **1745** may be used to determine the direction of flow of fluid **1727**. For example, in one embodiment if fluid **1727** is flowing from plug **1725** towards plug **1730** then check valve **1745** will be open and electrical continuity will be measured between the plugs. However, if fluid **1727** is flowing from plug **1730** to plug **1725** check valve **1745** will be closed and there will be no electrical continuity between plugs **1725** and **1730**. Similarly, continuity between plugs **1725** and **1735** may be used to determine position of valve **1740**. If there is continuity then valve **1740** is open and if there is no continuity then the valve is closed.

[0074] In some embodiments wall **1705** may be made from a transparent material while in other embodiments it may be made from a semi-transparent or an opaque material. In further embodiments fluid **1727** may be made from a transparent material while in other embodiments it may be made from a semi-transparent or an opaque material. In some embodiments a substantially transparent structure **1700** may be beneficial such as in an application that must pass light through the structure.

[0075] Myriad uses and other configurations are within the scope of this disclosure. For example, in some embodiments, laminar flow fluid channels may be used to form electrical circuits. In one embodiment, three parallel streams of fluid flow into a common unified channel. In a further embodiment, a conductive stream may be disposed on either side of a non-conductive stream. As long as the flow is laminar and the conductive stream continues to flow the first and second conductive streams may remain electrically isolated. However, in some embodiments, if one or more of the streams transitions to turbulent flow and/or the non-conductive stream is shut off, the conductive streams may combine and electrical continuity between the two conductive streams may result.

[0076] Now referring to FIG. **18**, an embodiment may use an electrically conductive transparent fluid for forming an electrical connection to an electronic device as well as for cooling. In this embodiment electrically conductive fluid flows over an light emitting diode (LED) die, making electrical contact with the LED die while simultaneously cooling it. The electrically conductive fluid that flows over the top of the die is transparent, allowing the LED to emit light through the fluid.

[0077] A simplified isometric view of structure **1800** is illustrated in FIG. **18** and includes a LED die **1805** held on either side by electrically insulative supports **1810**. LED die **1805** has an emission aperture **1815**, a first electrical contact **1820** and a backside **1825** which is also a second electrical contact. Structure **1800** further has a lower cover **1830** which may be opaque and an upper cover **1835** which may be transparent or translucent. Lower cover **1830** in combination with supports **1810** forms a first channel **1840** that may contain a first electrically conductive fluid **1845**. Upper cover **1835** in combination with supports **1810** forms a second channel **1850** that may contain an electrically conductive and transparent or translucent second fluid **1855**. Fluids **1845**, **1855** may be connected to one or more pumping device such that they flow through channels **1840**, **1850**, respectively.

[0078] LED die **1805** may emit light from emission aperture **1815** when a voltage potential is applied between first electrical contact **1820** and backside **1825**. First fluid **1845** may be at a first voltage potential and in electrical contact with backside **1825**. Second fluid **1855** may be at a second voltage potential and in electrical contact with first electrical contact **1820**. Thus, first and second fluids, **1845**, **1855**, respectively may not only flow across LED die **1805**, but may also apply the necessary voltage potential to the LED die to make it emit light. Further, the flow of first and second fluids **1845**, **1855**, respectively across LED die **1805** may provide cooling to maintain the temperature of the LED die below its maximum operating temperature. Yet further, the translucent or transparent nature of second fluid **1855**, enables LED die **1805** to emit light through the second fluid and through second cover **1835**. Such embodiments may enable direct liquid cooling of high power LED's without a need for forming wired electrical connections to LED die **1805**. Other embodiments may use different geometries or configurations and are within the scope of this disclosure.

[0079] Referring now to FIG. **19**, some embodiments may employ a transparent liquid crystal fluid to make a structure change color. As an example, wearable device **1900** may be similar to wearable device **500** (see FIG. **5**) having a transparent or translucent band **1905** that may contain one or more electrically conductive channels **1910(1)** . . . **1910(3)**. However, wearable device **1900** may have one or more illuminated portions that change color, as described in more detail below.

[0080] Band **1905**, may have one or more enclosed interior cavities **1915**, **1920**, **1925**. In some embodiments, cavities **1915**, **1920**, **1925** may each have a first wall **1930** oriented parallel to a second wall **1935**. In one embodiment, first wall **1930** may contain a light source and second wall **1930** may contain a polarization filter and/or a color filter. An optically transparent fluid (not shown) may be disposed within the one or more enclosed interior cavities **1915**, **1920**, **1925**. The fluid may be configured to change its crystalline orientation under an applied voltage such that in a first orientation light from the light source may pass through the fluid with relatively little effect and in a second orientation the fluid may change a polarization of the light.

[0081] For example, in one embodiment first wall **1935** may contain a white light source such as, for example, an

LED. The white light source may be configured to emit light through a first polarizer, then through the liquid crystal fluid towards second wall **1930**, oriented parallel to the first wall. In some embodiments the fluid may be a liquid crystal type of fluid that may be a twisted nematic or a super twisted nematic or other type. Second wall **1930** may have one or more polarizers and/or color filters.

[0082] In some embodiments, this configuration may enable band **1905** to be illuminated with one or more colors. In further embodiments, band **1905** may only have one fluid compartment and one color filter. In other embodiments, band **1905** may have numerous individual compartments with different color filters (e.g., red, green and blue) on the compartments such that the color of the object may be changed. For example, if a red color is illuminated adjacent to a blue color, the object may appear to be purple.

[0083] Now referring to FIG. **20**, another example of an embodiment that may use a transparent liquid crystal fluid to make a structure change color is illustrated. Wearable device **2000** is similar to wearable device **1900** (see FIG. **19**) having a transparent or translucent band **2005** that may contain one or more electrically conductive channels **2010(1)** . . . **2010(3)**. However, wearable device **2000** may have a relatively large number of comparatively small compartments such that the apparatus can display messages, images and/or myriad colors, as described in more detail below.

[0084] The mechanism that displays the colors and/or messages may be the same as employed in wearable device **1900**, however the size of the interior cavities may be substantially smaller. Further, the particular colors and/or the images generated by wearable device **1900** may be aesthetically appealing and may be difficult to achieve with other technologies. For example, in one embodiment the colors and tones are somewhat muted and may appear to be more of a glow than a bright illumination. In some embodiments these features may be used as an indicator to a user who may have the device on or near them.

[0085] In some embodiments combinations of the embodiments described above may be used. For example, in one embodiment a wearable device band may have one or more portions that change color. In some embodiments the one portion may change color from transparent to red when there is an incoming call. That same portion may also be a touch sensitive user input device such that a user may answer the call by touching the portion that changed color. In further embodiments a user may program portions to be various different colors corresponding to different commands. By touching that particular color the wearable device may execute a particular command associated with that color. Myriad other combinations of features and functions discussed herein are within the scope of this disclosure.

[0086] In the foregoing specification, embodiments of the invention have been described with reference to numerous specific details that may vary from implementation to implementation. The specification and drawings are, accordingly, to be regarded in an illustrative rather than a restrictive sense. The sole and exclusive indicator of the scope of the invention, and what is intended by the applicants to be the scope of the invention, is the literal and equivalent scope of the set of claims that issue from this application, in the specific form in which such claims issue, including any subsequent correction.

What is claimed is:

1. A flexible apparatus comprising:
an optically transparent and flexible shell forming an interior cavity;
a first and a second electrically conductive plug disposed through the shell;
an electrically conductive fluid disposed within the enclosed interior cavity such that the electrically conductive fluid contacts the first and the second electrically conductive plugs and forms an electrical connection between the first and the second electrically conductive plugs.

2. The flexible apparatus of claim **1** wherein the fluid is optically transparent.

3. The flexible apparatus of claim **1** wherein an electrical resistance between the first and second electrically conductive plugs changes when the shell is deflected.

4. The flexible apparatus of claim **1** wherein the fluid is configured to operate as a conductive element of a capacitive sensor such that the sensor can detect when a user touches the shell.

5. The flexible apparatus of claim **1** wherein the fluid has a void that can be positioned on the first electrically conductive plug such that the fluid is not in electrical contact with first electrically conductive plug.

6. The flexible apparatus of claim **1** wherein the fluid flows through the interior cavity and an insulative valve having a first position where the fluid flows past the valve and a second position where the valve stops the flow of the fluid and electrically isolates the fluid on an upstream side of the valve from the fluid on a downstream side of the valve.

7. The flexible apparatus of claim **1** wherein the fluid is electrically connected to a ground and functions as an electromagnetic interference shield.

8. The flexible apparatus of claim **1** wherein the fluid is coupled to an antenna circuit and functions as an antenna.

9. A transparent circuit comprising:
a shell that is transparent to optical signals;
at least one interior cavity formed within the shell;
an electrically conductive fluid that is transparent to the optical signals and is disposed within the at least one interior cavity and;
a first and a second electrically conductive plug disposed through the shell and configured to be in contact with the electrically conductive fluid.

10. The transparent circuit of claim **9** wherein the shell is placed in front of an optical sensor and the optical sensor emits or receives optical signals through the transparent circuit.

11. The transparent circuit of claim **9** wherein the electrically conductive fluid acts as a conductive element of a capacitive sensor such that the sensor can detect when a user touches the shell.

12. The transparent circuit of claim **9** wherein the shell is made from a flexible material.

13. The transparent circuit of claim **9** wherein the shell has a first end and a second end with the at least one interior cavity extending from the first end to the second end and a first electrically conductive plug is secured in the first end and a second electrically conductive plug is secured in the second end such that the at least one interior cavity is sealed forming an electrically conductive channel between the first and the second electrically conductive plugs.

14. The transparent circuit of claim **9** wherein the shell and the fluid are made from optically transparent materials.

15. The transparent circuit of claim **9** wherein the fluid is configured to flow through the interior cavity.

16. The transparent circuit of claim **15** wherein the interior cavity has an electrically insulative valve and the first electrically conductive plug is on a downstream side of the valve and the second electrically conductive plug is on an upstream side of the valve.

17. The transparent circuit of claim **16** wherein the valve is a check valve.

18. An apparatus comprising:

an optically transparent shell having one or more enclosed interior cavities, each of the one or more cavities having a first wall oriented parallel to a second wall, the first wall containing a light source and the second wall containing a polarization filter;

an optically transparent fluid disposed within the one or more enclosed interior cavities, the fluid configured to change its crystalline orientation under an applied voltage such that in a first orientation light may pass through the fluid with relatively little effect and in a second orientation the fluid may polarize the light.

19. The apparatus of claim **18** wherein the second wall comprises a color filter.

20. The apparatus of claim **19** wherein the light source is a white light source.

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